

# Animal genetic resource trade flows: The utilization of newly imported breeds and the gene flow of imported animals in the United States of America<sup>☆,☆☆</sup>

Harvey Blackburn<sup>a,\*</sup>, Douglas Gollin<sup>b</sup>

<sup>a</sup> National Animal Germplasm Program, National Center for Genetic Resources Preservation, ARS, USDA, USA

<sup>b</sup> Williams College, Williamstown, MA, USA

---

## Abstract

Animal germplasm exchange has recently received attention as a product of the FAO's State of the World's Animal Genetic Resources effort. Some have advocated a need to explore policies and regulations on the exchange of germplasm (e.g., Hiemstra, S.J., Drucker, A., Tvedt, M., Louwaars, N., Oldenbroek, J., Awgichew, K., Kebede, S., Bhat, P., da Silva Mariante, A. 2006. Exchange, use and conservation of animal genetic resources: policies and regulatory options. Centre for Genetic Resources. Wageningen Univ., the Netherlands, pp. 1–43). However, there has been little comprehensive assessment of either the economic or genetic impact of introduced germplasm into national populations. As a result, much of the discussion of gene flows has been based on assumptions and generalizations. The objective of this paper is to evaluate the genetic impact of germplasm imported into the United States during the last 25 to 50 years. The paper considers both new breeds (Meishan pigs, Tuli cattle, and Boer goats) and new animals within existing breeds (Limousin and Jersey cattle). Of the new breeds recently imported only one had an impact on US animal agriculture. Neither the Tuli nor the Meishan has impacted the US livestock industry. It appears that these breeds were initially viewed as attractive because of single traits, but producers did not find it attractive to adopt the new breeds based on these specific traits. In the end, these breeds did not prove competitive in the US under the current set of market conditions. This result would indicate that importation of new genetic resources due to a single trait of interest is not a viable importation strategy. By contrast, the Boer goat exhibited a number of production characteristics which made it desirable to US producers and thereby allowed the breed to become well established. A second portion of the study evaluated the importation and parentage pattern of Limousin cattle as they became established in the U.S. and the gene flow of imported Jersey cattle since the 1950's. In both cases, the study relied on pedigree analysis. Over the past fifty years, Jersey cattle have been sporadically imported from various countries, but no imported animal has had an overpowering effect on the population. It appears that by the great-grand progeny level, the genes from imported animals are diminishing rather than increasing in the population. In evaluating the predicted transmitting abilities for imported cattle relative to high and moderately ranked domestically bred cattle, there were significant differences between these groups for milk production. This would be sufficient to explain why the impact of the imported cattle diminished. The results of our analysis at both the breed and individual level underscore the speculative nature of germplasm importation — even within breeds where there is a great deal of information available about production characteristics. From this analysis, we conclude that successful importation of new breeds into the US must be based on a large number of production characteristics; importation for a single characteristic (e.g., high prolificacy) while the breed is deficient in other areas does not

---

<sup>☆</sup> Mention of a trade name, proprietary product, or specified equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable. All agency services are available without discrimination.

<sup>☆☆</sup> This paper is part of a special issue entitled Animal Genetic Resources, Guest Edited by Ricardo Cardellino.

\* Corresponding author. National Center for Genetic Resources Preservation, ARS, USDA 1111 South Mason St. Fort Collins, CO. USA. 80521. Tel.: +1 970 495 3268; fax: +1 970 221 1427.

E-mail address: [Harvey.Blackburn@ars.usda.gov](mailto:Harvey.Blackburn@ars.usda.gov) (H. Blackburn).

lead to the breed's adoption. While not fully explored in this work, it appears that initial interest and acceptance from the private sector is crucial for breed acceptance, as the Boer goat demonstrates. Within an existing breed, importation of individual animals still appears to have a relatively high degree of risk and is dependent upon the importer's ability to pick viable candidates. However, once animals are imported their progeny must effectively compete with the domestic population, or else their genetic contribution will rapidly diminish.

Published by Elsevier B.V.

**Keywords:** Animal genetic resources; Gene flow; Germplasm trade

## 1. Introduction

Through human history, societies have a history of exchanging animal genetic resources as livestock keepers and (later scientists) have sought gene combinations that result in improved productivity and profitability. Numerous historical accounts (Dohner, 2001; Rodero et al., 1992) detail the movement of genetic resources from one geographic region to another where the new breed either succeeds permanently, fails decisively, or succeeds for a period before falling out of favor. The dynamic nature of these transitions was probably little different from the patterns that occur today in the global livestock sector. Recently, questions have been raised about the international exchange of genetic resources (FAO, 2007; Hiemstra et al., 2006). The concerns are centered on the importation of ill-suited animal genetic resources (AnGR) into developing countries and about the market prices and contractual terms of these genetic inflows. There are many examples detailing unsuccessful “North” to “South” movements of AnGR due to inappropriate matching of genotype to the environment (Madalena et al., 2002). However, there has been little published on South–North and North–North gene flows.

In the following companion paper (this issue), we explored the economic patterns of AnGR flows. Our analysis showed that recent trade flows have been predominantly North–North and to a lesser extent North–South, while South–North flows are principally restricted to nearby countries with fairly minor differences in environment and in production systems (e.g., Hungary–Greece, Romania–Turkey, Panama–Mexico). Therefore, one of the conclusions of that paper was that Northern breeders appear to exhibit little interest in Southern genotypes.

To expand our evaluation of international germplasm movements, this paper explores how newly imported breeds have performed when transferred to U.S. production systems. We also ask how individual imported animals have impacted the genetics of well established breeds. Where possible, we compare performance levels of imported and domestic animals to understand producers' decisions. Each breed is unique and therefore has its own “history,” but there are important lessons from the ways that imported breeds and animals have been used.

## 2. Materials and methods

To assess the impact of imported genetics we performed two types of analysis. First, we undertook a literature review to examine how newly imported breeds compared to existing breeds for performance characteristics. The three new breeds used for the study were: Meishan pig, Tuli cattle, and Boer goat. These breeds were chosen because their importation dates occurred after 1980 and the breeds have very distinct features. Second, we analyzed data on the importation of new animals and the subsequent utilization of their genetics for two cattle breeds: one relatively new to the U.S. (Limousin) and one that was an established breed (Jersey). The analysis was based on pedigree records. Specifically, we counted the number of progeny, grand progeny and great great-grand progeny from the imported animals. Both Limousin and Jersey pedigree records were obtained from the relevant U.S. breed associations. The Jersey analysis includes all non-Canadian imported Jersey cows and bulls from 1950 to 2003. The Jersey analysis does not include importations from Canada, due to the volume and frequency of trade between the two countries. The Canadian–U.S. pedigrees are complicated because in many instances breeding animals are exported but their descendants – one or two generations later – could be re-imported. Using these data, we computed for each imported (non-Canadian) animal the number of progeny, grand progeny and great-grand progeny. By tracing the pedigree to this level, it was possible to see if the resultant genetic influence of importations increased as a percentage of the total number of Jerseys registered.

## 3. Results

### 3.1. Genetic impacts of importations

Even if small numbers of breeding animals (or semen or embryos) are traded, they can have large impacts on the genetic makeup of livestock herds and flocks via selection, breeding and utilization of assisted reproductive technologies. The following section explores several cases of germplasm importation to the United States.

Table 1

Percent of cattle registered in 2000 for various cattle breeds by geographic origin of the breed

British breeds		US US-developed British-tropical composite breeds		Tropical breeds		European breeds	
Angus	36.4	Beefmaster	4.3	Brahman	1.1	Charolais	6.1
Hereford	13.2	Braford	0.4	Tuli	0.0	Gelbvieh	7.4
Red Angus	6.9	Red Brangus	0.4	Senepol	0.1	Limousin	6.4
Shorthorn	3.1	Santa Gertrudis	1.1			Maine-Anjou	1.8
						Salers	1.9
						Simmental	5.8
Total	59.7		6.3		1.3		29.4

For new importations, success can be evaluated by the number of animals a breed society registers in a given year. While such numbers are biased estimates (only viable breeding animals are registered) their relative size when compared to other breeds does provide insight into the importance of a specific breed. As an illustration, consider the case of beef cattle. Table 1 reports registered beef cattle in the US by breed, with the various breeds categorized by country or region of origin. British-origin breeds are, by a large margin, the most common. During the late 1960s, there were significant importations of new breeds from continental Europe to the US (termed North–North exchange in the companion paper). Table 1 illustrates that as a group these breeds are numerically important (29% of registrations) and have become commonly used by the beef cattle industry. That said, they do not seem to have dislodged from dominance the traditionally popular Hereford and especially Angus (with over 225,000 registrations in 2000). US-developed composite breeds have seen some success; these composites bring together traits from British breeds and *Bos indicus* traits. Pure tropical breeds (representing a South–North exchange) are locally important in southern beef cattle production systems, but in terms of registrations they lag far behind the British breeds.

While Table 1 does provide insight in terms of registered cattle, it does not provide insight about the commercial beef industry's utilization of different breed types; some breeds may have genetic impacts through cross-breeding. This impact may be greater than breed registration numbers might suggest. For example, it is thought that 30 to 50% of the commercial cattle in the southern US have from 12 to 75% *B. indicus* genes. Put into a national context, such estimates would increase the role of such genotypes. However, interviews with breed association secretaries suggest that there have been no recent importations of *B. indicus* cattle that have had major impacts on the respective breeds nor the commercial beef cattle sector. Such insight suggests that once a breed is imported and becomes established, the

domestic industry quickly loses its dependence upon the source of the imported genetic resources as it modifies the genetics to meet domestic market conditions.

### 3.2. Recent importations: case studies

To provide insight on how imported genetic resources are used initially and then developed, we examined relatively recent breed importations in different species. The importation episodes considered are: the Meishan pig from China, Tuli cattle from Zimbabwe, and the Boer goat from South Africa.

#### 3.2.1. Meishan pigs

During the 1980s, the US research community and the swine industry perceived a need to increase reproductive rates as a means of improving production efficiency and profitability. It was known that certain Chinese swine breeds were highly prolific. The U.S. Department of Agriculture (USDA) and land grant universities collaborated to import the Meishan breed from China with a goal of exploring its prolificacy in U.S. production systems. Young (1992) evaluated the imported breeds performance and found the Meishan pigs were prolific, relative to existing U.S. breeds. However, the Meishan pigs lacked a number of growth and body composition characteristics desired by producers in the U.S. (Table 2). Due to these limitations the breed was deemed inappropriate for U.S. production systems and the germplasm was never incorporated into the commercial sector. Public and private sector geneticists realized they could select within U.S. breeds

Table 2

Comparison of productivity between the progeny of Duroc and Meishan boars

Breed	Daily gain from 126–154 d (g)	Back fat (mm)	Age at 99.7 kg (market weight)
Duroc	899	18.6	169
Meishan	750	26.9	181

From Young (1992).

for increased litter size and not contend with the undesirable characteristics of the Meishan. While the Meishan was not useful for industry, it did prove useful in genomic studies due to the genetic distance from US breeds (Rohrer et al., 1999).

### 3.2.2. Tuli cattle

The Tuli was developed in the semi-arid environments of Zimbabwe during the first half of the 20th century. Tuli cattle were imported into the U.S. via Australia in 1991. At the time of the importation, it was thought that the Tuli might be a *Bos taurus* breed that would be well suited to arid/semi-arid environments in the Southern U.S. and would not have some of the recognized limitations of *B. indicus* cattle breeds. The performance of the Tuli was evaluated by a number of state and federal experiment stations. These stations included sub-tropical, semi-arid, and temperate ecosystems. The general conclusion from the research (Table 3) was that Tuli-sired calves weighed less at weaning, grew slower in the feedlot phase of production, and had lighter carcass weights (Cundiff, 2005; Sanders et al., 2005; Holloway et al., 2005). Tuli cows did rank well for a measure of biological efficiency when compared to Angus/Hereford cows (Jenkins and Ferrell, 2005) and were more tender than Brahmans but not Herefords (Wheeler et al., 2005).

Some producers did form an association for the maintenance of pedigrees and promotion of the breed. But in spite of the initial enthusiasm about Tuli cattle, after a decade, there were only 150 registrations in 2000 (Blackburn et al., 2004), and the level of interest has waned. Performance levels of the Tuli under farm-level conditions in the US were not sufficient to attract new breeders or commercial cattlemen. Thus, the Tuli serve as an example of an imported breed that has not made an impact on the US cattle industry.

### 3.2.3. Boer goat

South African Boer goats were imported into the U.S. in 1993 from New Zealand and later from Australia (due

Table 4

Comparison of Boer and Spanish goat performance

Breed	Mature weight, kg <sup>a</sup>	Weaning weight, kg <sup>a</sup>	Litter weight weaned, kg <sup>b</sup>	Litter size/doe <sup>b</sup>
Boer	68.5	27.3	53.5	1.51
Spanish	47.5	25.3	66.7	1.79

<sup>a</sup> Dzakuma et al. (2002).

<sup>b</sup> Browning et al. (2006).

to the U.S. embargo placed upon South African importations due to the policy of apartheid) and South Africa. The importations were arranged and promoted by the private sector. The breed has a combination of traits (e.g., larger body size and faster growth rate) that other U.S. meat goat breeds lacked. In addition, the breed exhibited a level of body conformation, which facilitates marketing, not typically found in US goat populations (Table 4). The breed has contributed increased size and growth rate to the U.S. goat industry. As a result the breed has been widely adopted — as evidenced by the 45,000 registrations in 2005.

While the Boer importation has proven successful, it has not been without negative impacts. Blackburn (1995) illustrated how the breed's performance might be compromised in limited forage conditions and the recent work of Browning et al. (2006) also showed that under Tennessee forage conditions the Spanish does had higher reproductive rates. Furthermore, the Boer is displacing and creating a contraction of genetic diversity in Spanish goats. The Spanish goat was the predominant meat goat breed prior to the importation of the Boer and has been in North America since the 1500s. Thus, in some sense, the Boer importation has threatened “indigenous” breeds in the same way that developing country animal genetic resources have been threatened by the introduction of high performance breeds of cattle, swine, and poultry.

### 3.3. Post-importation gene flow

The previous examples provide insight into the importation of new breeds to the US. Once a breed does become established, how frequently do breeders return to the country of origin and make additional importations (presumably to resample or broaden the genetic base)? This question was examined using pedigree information on Limousin cattle. This breed was originally imported from France in the late 1960's, and it was a successful introduction. We analyzed pedigree data to determine the number of progeny, grand progeny, and great great-grand progeny produced by imported animals. Fig. 1 illustrates that once the breed was imported and a sufficient number

Table 3

Comparison of Tuli, Hereford and Brahman cattle for various traits

Breed	Weaning weight, kg <sup>a</sup>	Post-weaning weight gain, kg/day <sup>a</sup>	Tenderness <sup>b</sup>	Carcass weight, kg <sup>b</sup>
Hereford	240	1.38	9.7	350
Brahman	246	1.20	13.2	333
Tuli	224	1.15	10.1	309

<sup>a</sup> Cundiff (2005).

<sup>b</sup> Wheeler et al. (2005).

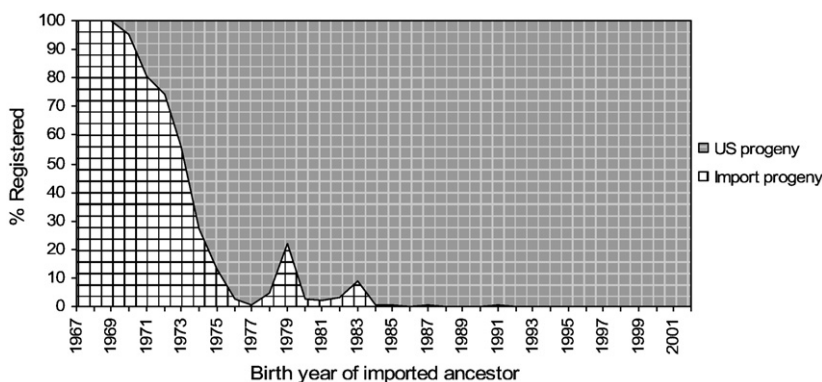


Fig. 1. Percentage of US and imported progeny registered for Limousin cattle.

of animals attained, additional germplasm imports from the country of origin were infrequent. After the first decade – when the breed was still becoming established and imports were used to establish adequate breeding stock – there was an additional set of imports and their resulting progeny that peaked in 1979 and then dropped to zero in 1984. It is speculated that the smaller peaks in 1979 and 1983 represent animals imported to broaden the breed's genetic base. However, after 1984 additional importations were minimal and did not result in significant numbers of progeny being registered. This has led us to conclude that producers had a broad enough genetic base, and within a relatively short time period, it was more advantageous (economically and biologically) for breeders to work with the genetic resource in the U.S. rather than to import additional genetics. This example suggests that the imported animals are subject to selection strategies, in the new country, that initiates development of a divergent sub-population and as a result, within a few generations, domestically bred animals are better suited to domestic production conditions.

In addition to new breed importations, there have been additional importations of genetic resources for breeds that have been in the US for a century or more. Jersey dairy cattle are exemplary of this situation as they

where first imported into the US during the 19th century from the United Kingdom (UK). Furthermore, over the last half century there have been Jersey importations from a number of countries (Table 5). Imports from the UK are the most numerous and have resulted in the largest number of progeny registered in the US. Imports from Australia, Germany and France seem to have had little impact on the breed.

Table 6 compares the average numbers of registered progeny for imported animals with the numbers of progeny for animals with no recently imported ancestors. Imported bulls have a larger mean progeny number (perhaps due to the importer seeking to fully evaluate and market the imported animal, thereby recuperating the costs associated with importation). However, in terms of maximum progeny, grand progeny and great-grand progeny numbers per bull, the top imported bull lagged behind his US counterpart by a tenfold difference. This result would imply that no high impacting Jersey sire has been imported in to the US. To further understand the

Table 5  
Number of Jersey cattle imported into the U.S. from 1950 to 2003 and the resulting progeny by exporting country

Country	Number imported	Progeny	Grand progeny	Great-grand progeny
Australia	22	472	282	2
Germany	1	239	276	228
Denmark	35	6458	8577	6005
Great Britain	79	237	5865	26,799
New Zealand	48	1171	1263	1641
France	1	1	0	0

Table 6  
Mean and maximum progeny numbers for imported and U.S. derived Jersey cattle from 1950 to 2003

Source	Mean progeny, grand progeny, and great-grand progeny number	Sum of progeny, grand progeny, great-grand progeny (number of progeny, grand progeny, and great-grand progeny)
Imported bulls	65.9	10,701 (3049; 6127; 1525)
Imported cows	1.4	4
U.S. bulls	33.1	232,494 (30,872; 93,227; 108,395)
U.S. cows	1.8	73
Top bull relationship to 2004–2005 registered cattle: US — 0.167; Import — 0.097.		



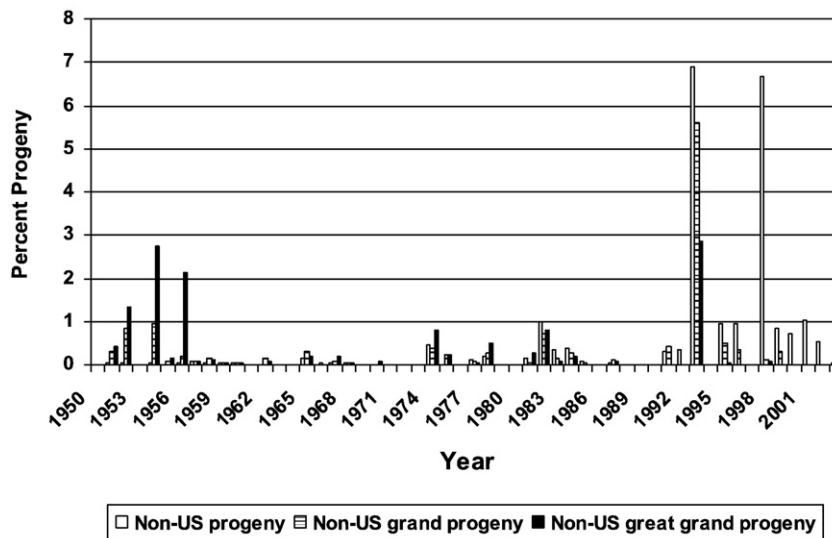


Fig. 2. Percent of non-US progeny, grand progeny, and great-grand progeny Jersey registered by year (note scale ranges from 0 to 8%).

impact of importations, Fig. 2 shows the percent of Jersey cattle registered in the U.S. from 1950 to 2003 that were, respectively, progeny, grand progeny, and great-grand progeny of an imported sire and/or dam. These results indicate that the impact of the importations increased in the early 1990's, but only by a modest amount. This result is especially interesting given that the dairy industry makes the greatest use of artificial insemination and computation of individual animal genetic merit; there should be little producer bias towards domestic animals. In addition, dairy management systems are generally assumed to be similar across countries, suggesting that elite animals from abroad should have useful genetics for US production systems. These results, however, seem to suggest that there are significant environmental differences between these countries.

To explore the differences in performance between imported and US-bred Jerseys, a subset of the data set was used. The subset was comprised of bulls born between 1980 and 1995. Within this birth-year classification, there were 39 imported bulls, 50 high-performing bulls (defined as top producing/highest number of progeny), and 51 bulls that ranked average for number of progeny and performance. The 140 bulls were reduced

to 66 head (11 imported, 46 high merit, and 9 average merit) based on the presence of performance information. An ANOVA was performed with the three groups as a class variable and two year groups (bulls born in the 1980s vs 1990s), year groups and the interaction between the two main effects were non-significant. Table 7 compares the differences between the three groups of bulls. Interestingly, the imported bulls rank significantly better for net merit and milk fat when compared to the US-average and US-high bulls. However, the US-high bulls significantly out performed the imported bulls for milk production, suggesting that the very large discrepancy between US-high and imported bulls for milk production is the primary factor governing their popularity among breeders.

The Jersey data suggest that non-North American importations have had very temporary and limited impacts on the US Jersey population. While the imported animals appeared to rank well for some measures of production, their lower rankings for milk production may explain why they did not impact the US population. At the individual animal level, the data suggest that no Jersey import achieved a high level of popularity (Table 6).

Table 7

Predicted transmitting abilities for imported, U.S. high and U.S. average bulls born between 1980 and 1995

Group	Net merit	Milk	Fat	Protein	JPI	Productive-life
Import	119.9 <sup>a</sup>	−326.8 <sup>b</sup>	40.1 <sup>a</sup>	5.7 <sup>a</sup>	42.0 <sup>a</sup>	0.05 <sup>a</sup>
U.S. high	34.6 <sup>b</sup>	194.5 <sup>a</sup>	10.0 <sup>b</sup>	4.7 <sup>a</sup>	16.3 <sup>a</sup>	0.07 <sup>a</sup>
U.S. average	−206.5 <sup>c</sup>	−693.7 <sup>b</sup>	−17.3 <sup>c</sup>	−21.4 <sup>b</sup>	−108.0 <sup>b</sup>	−1.95 <sup>b</sup>

<sup>abc</sup>Values in the sample column with different superscripts are significantly different at  $P < 0.05$ .

#### 4. Conclusions

Livestock breeders have had a long history of evaluating and utilizing imported genetic resources. Such efforts predate the work of Bakewell. While the capacity to move and test a variety of genetic resources has increased, the driving force remains the same: a search for gene combinations that will yield increased profitability. As with earlier importation efforts, the success of an importation – either as a new breed or individual animal of an existing breed – is dependent upon the imported breed or animal being able to compete effectively with existing populations. At the breed level, several conclusions can be drawn from the three importation examples. The Boer importation demonstrated that for a breed to become economically viable it must offer clear and significant advantages that are currently not found in existing livestock populations. In the case of Boer goats, the advantages were growth rate, a large body size, and a desirable carcass. Despite the Tuli's productivity in semi-arid environments and acceptable meat tenderness, these traits were not sufficient to compensate for its smaller body size and slower growth rate. As a result, the Tuli has not attracted cattle producers' interest, as suggested by registration numbers. The general conclusion drawn from the Meishan pig importation is that while a breed may have a specific trait of interest, other economically important production characteristics must be present at sufficient levels or the industry will not adopt the new population.

From this review of imported breeds, several elements appear to be essential for a breed to be successfully imported. First and foremost, the breed must be able to produce competitively in the environment/production system used by the breeders. Second, it appears the breed must have several positive attributes which distinguish it from other breeds currently being used (unlike plants), and detrimental characteristics must be minimal. Third, the breed must achieve a level of breeder interest and momentum that will increase the size of the population, attract (and maintain) new breeders, and potentially stimulate new imports to broaden the gene pool.

US importers seek non-US livestock genetics that have the potential to increase productivity. To engage in successful importation, the importer must be able to select individual animals that can outperform the U.S. population. The Jersey importations demonstrate that it is difficult, even with the advanced performance information of the dairy industry, to select individual animals that will be competitive in the U.S. This

suggests that even for North–North exchanges, where both importer and exporter production systems could be considered highly productive, there are potentially significant genetic–environmental interactions that make successful importation a speculative process.

Importations of non-OECD animals face the additional challenge of coming from environments and management systems that may differ greatly from US systems. In general, this means that a successful import would need to be genetically superior for multiple traits — not just for a single trait. But this is a difficult burden to meet, especially since environmental and managerial factors may mask the genetic potential of animals coming from the developing world. The Meishan and Tuli importations are examples of breeds that have interesting characteristics in their countries of origin but have not proven successful under US production and market conditions. The Meishan example demonstrates that importing animals for the incorporation of a single trait may not be an effective strategy for the livestock industry, although it is commonly used in plant breeding. The main impediment to introgressing genes from non-OECD breeds has been – and will likely continue to be – the genetic correlations between desirable and undesirable traits. To acquire the beneficial characteristics of these animals, the breeder must embark on a lengthy breeding program to eliminate negative characteristics (e.g., fat content).

Despite the obstacles to successful importation, livestock breeders will undoubtedly continue to seek new and different genetic resources to evaluate. The recent history of livestock importations would suggest that animals from OECD countries will continue to be potential targets for importation into the U. S. However, emphasis will generally be on broad-based measures of performance, rather than single traits. Molecular techniques may eventually alter the potential for introgressing single genes, and thereby change the attractiveness of exotic imports. Nevertheless, at present, this analysis would suggest that there is little demand by US animal agriculture for imported germplasm other than that originating from other OECD countries with high performance production systems.

#### Acknowledgements

The authors thank Cari Wolf of the American Jersey Cattle Association and Kent Andersen of the North American Limousin Foundation for providing Jersey and Limousin data, respectively; and Carrie Welsh of NAGP-ARS-USDA for data preparation.

## References

- Blackburn, H., 1995. Comparison of performance of Boer and Spanish Goats in two U.S. locations. *J. Anim. Sci.* 73, 302–309.
- Blackburn, H.D., Stewart, T., Bixby, D., Siegel, P., Bradford, E., 2004. United States of America Country Report for FAO's State of the World's Animal Genetic Resources. [http://www.ars-grin.gov/animal/US\\_SOW\\_report.pdf](http://www.ars-grin.gov/animal/US_SOW_report.pdf) (accessed August 1, 2007).
- Browning, R., Payton, T., Donnelly, B., Leite-Browning, M., Pandya, P., Hendrixson, W., Byars, M., 2006. Evaluation of three meat goat breeds for doe fitness and reproductive performance in the southeastern U.S. 8th World Cong. Genet. Appl. Livest. Prod. 32 (11), 1–4.
- Cundiff, C.V., 2005. Tropically adapted breeds in a temperate environment: calving, growth, reproduction, and maternal traits. Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 131–143.
- Dohner, J.V., 2001. *Historic and Endangered Livestock and Poultry Breeds*. Yale University Press, New Haven.
- Dzakuma, J.M., Risch, E., and Blackburn, H.D. 2002. Goat growth model: Genotype X nutritional environmental interactions. Proc. 7th World Congress on Genetics Applied to Livestock Production 31, 237–240.
- FAO, 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture*. FAO, Rome, Italy.
- Hiemstra, S.J., Drucker, A., Tvedt, M., Louwaars, N., Oldenbroek, J., Awgichew, K., Kebede, S., Bhat, P., da Silva Mariante, A., 2006. Exchange, use and conservation of animal genetic resources: policies and regulatory options. Centre for Genetic Resources. Wageningen Univ., the Netherlands, pp. 1–43.
- Holloway, J.W., Warrington, B., Forest, D., Randel, R., 2005. Lifetime performance and efficiency of F1 tropically adapted beef cattle breeds × Angus in semiarid rangelands. Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 118–125.
- Jenkins, T., Ferrell, C., 2005. Feed utilization and performance of crossbred tropically adapted cattle. Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 162–166.
- Madalena, F., Agyemang, K., Cardellino, R., Jain, G., 2002. Genetic improvement in medium-to low-input systems of animal production. Experiences to date. 7th WCGALP, vol. 33, pp. 331–340.
- Rodero, A., Delgado, J., Rodero, E., 1992. Primitive Andalusian livestock and their implication in the discovery of America. *Arch. Zootec.* 41, 383–400.
- Rohrer, G.A., Ford, J., Wise, T., Vallet, J., Christenson, R., 1999. Identification of quantitative trait loci affecting female reproductive traits in a multigenerational Meisan-White composite swine population. *J. Anim. Sci.* 77, 1385–1391.
- Sanders, J.O., Riley, D., Paschal, J., Lunt, D., 2005. Evaluation of F1 crosses of five *Bos indicus* breeds with Hereford for birth, growth, carcass, cow productivity, and longevity characteristics. Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 96–107.
- Wheeler, T.L., Shackelford, S., Koohmaraie, M., 2005. Carcass and meat traits of tropically adapted breeds evaluated at the U.S. Meat animal research Center. Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 154–161.
- Young, L.D., 1992. Effects of Duroc, Meishan, Fengjing and Minzhu boars on productivity of mates and growth of first cross progeny. *J. Anim. Sci.* 70, 2020–2029.